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by

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Submitted in partial fulfillment of
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ABSTRACT

The quality assurance program instituted by the Bureau of Ships in 1960 is intended to reduce the probability of material defects and failures in the ships constructed, overhauled, and repaired in our Naval (and private) shipyards. Particular emphasis is given to critical ship systems and to critical industrial processes which could affect the safety or the mission capabilities of the ships.

This paper represents a review of the quality assurance program as it now exists in the Naval shipyards under the direction and guidance of the Bureau of Ships. The principal elements of the program are discussed. Those areas of the program which appear to need further attention are cited.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	THE QUALITY ASSURANCE PROBLEM AND DEFINITIONS OF KEY TERMS	1
	The Quality Assurance Problem	2
	The Program	2
	Purpose	3
	Limitations	3
	Summary	3
	Definitions of Key Terms	4
II.	HISTORY OF QUALITY ASSURANCE	9
	Initial Department of Defense Actions	9
	Bureau of Ships Actions	10
III.	THE QUALITY ASSURANCE PROGRAM	12
	Planning for Quality Assurance	13
	The Need for a Plan	13
	Establishing the Quality Assurance Plan . . .	14
	Organization for Quality Assurance	17
	The Assurance Engineering Office	17
	The Shipyard Quality Assurance Organization .	17
	Design Aspects of Quality Assurance	20
	Design Functions	20
	Planning and Estimating Tasks	22
	Levels of Essentiality	23
	The Three Levels of Essentiality	23
	Modified Policy on Levels of Essentiality . .	24

CHAPTER	PAGE

Feedback 26

Navy Feedback Systems 27

Material Control 30

Procurement Documents 30

Vendor Quality Assurance Programs 31

Material Receipt Inspection 32

Identification Markings 33

Inspection and Text 35

The Inspection System 35

Quality Assurance Audits 37

Planned Audits 37

Certification of Sea Trails 37

Cost of Quality Assurance 40

Cost of Quality Versus Need 40

Human Factors 43

Motivation and Training 43

Zero Defects Program 44

IV. SUMMARY AND CONCLUSIONS 47

BIBLIOGRAPHY 57

APPENDIX 60

CHAPTER I

THE QUALITY ASSURANCE PROBLEM AND DEFINITIONS OF KEY TERMS

In the past, the only proof that was expected to show that a ship met its specifications or contractual requirements was the actual performance of the ship. This may have been an adequate measure since the ships were designed with large factors of safety and seldom, if ever, subjected to the maximum designed characteristics.

Ever increasing demands for performance and reliability are being placed on the modern Naval ship. The ship being built today can be expected to operate under highly adverse conditions. The ability to perform, or even survive, under these conditions must be built into the ship. It is necessary to know beforehand that the ship will perform satisfactorily prior to subjecting it to extreme conditions such as that encountered by a modern submarine diving to design depth.

Therefore, it is mandatory that the fleet be provided with every practicable assurance that the ships being built, overhauled, and repaired in our shipyards (public and private) will perform safely, efficiently, and effectively. The only known way of achieving this goal is through an effective quality assurance program.

THE QUALITY ASSURANCE PROBLEM

Assurance that the quality and reliability requirements are achieved is the responsibility of the organizations involved in creating a ship or other end product. Here, it is important to differentiate between quality, reliability, and quality assurance. Quality is considered to be that which is established by standard procedures and methods to result in a physical product. Reliability is the probability that the product will perform its intended function for a specified period of time under stated conditions. Quality assurance, on the other hand, is comprised of all the actions necessary to provide adequate confidence that the product will perform operationally as intended.

The Program

As used in this paper, quality assurance is a program. It is a detailed program that is used to assure quality at each stage the product goes through from conception to operational use. For a ship, this includes the processes of design, procurement, material control, manufacturing/production, inspection, testing, feedback, and, finally, auditing to verify that these processes are carried out as planned. It is necessary that the quality assurance actions not only result in a ship that will perform satisfactorily and reliably, but that they also result in objective evidence to provide adequate confidence that the ship will do so.

In order to achieve the objectives of the quality assurance program, it is first necessary to do the planning, organizing, staffing, establishing of policies and procedures, training, and assigning of authority and responsibility within the organizations involved. Since the initiation of a quality assurance program in 1960, the Bureau of Ships and its family of Naval shipyards have moved toward this goal. The program, however, is still

relatively new.

Purpose.

The purpose of this study was to review the quality assurance program in its present state of development in the Naval shipyards under the direction and guidance of the Bureau of Ships and to determine where deficiencies in management exist, if any.

Limitations.

The study reported here was conducted under the stress of limited time and reference material as well as the problem of not being able to interview a representative sample of the personnel directly involved. Therefore, the reader is cautioned against considering this paper to be the result of a complete study of the shipyard quality assurance program.

Summary.

The fleet deserves the assurance that the modern Naval ship, after completion of shipyard work, will perform satisfactorily, reliably, and safely. The quality assurance program recently instituted by the Bureau of Ships is intended to provide such assurance. This paper represents a review of the quality assurance program as it now exists in our Naval shipyards under the direction and guidance of the Bureau of Ships.

DEFINITION OF KEY TERMS

Various definitions exist for many of the words and terms used in quality assurance. The following glossary defines the pertinent quality assurance terms as they are used in various Bureau of Ships directives and U. S. Government Printing Office publications on quality control and reliability.

Acceptable Quality Level (A.Q.L.)	A nominal value expressed in terms of percent defective, or defects per hundred units, whichever is applicable, for a given group of defects of a product. (MIL-STD 109A)
Audit	The analysis and evaluation of procedures, methods, and records to determine compliance with existing requirements. (Derived from "surveillance" and "verification" definitions in MIL-STD 109A)
Certificate of compliance	A supplier's statement or record of quality, which includes objective evidence resulting from his inspection and testing of the product, that may be accepted as an element in determining whether the product is in conformity with the contract. A certificate of compliance that contains no actual test, inspection, or other verifiable date is unacceptable. (BuShips Instruction 4355.13)
Characteristic	A physical, chemical, visual, or any other measurable property of a product or material. (MIL-STD 109A)
Checking (design)	A recognized design process of surveillance at various steps in plan production. (Accepted industrial usage.)
Classification of defects	A list of possible defects of the unit of product, classified according to their importance. Defects shall normally be grouped into the classes of critical, major, or minor defects; but, defects may be grouped into other classes, if applicable. (MIL-STD 109A).

Component	A self-contained combination of parts, subassemblies, or assemblies, which perform a distinctive function in the overall operation of an equipment. (Used synonymously with preferred term "unit.") (MIL-STD 721 Navy)
Confidence level	The probability that a given statement is correct, or, the chance that a given value lies between two confidence limits. (The confidence interval.) (MIL-STD 721 Navy)
Critical defect	A defect that judgment and experience indicate could result in hazardous or unsafe conditions for individuals using or maintaining the product; or, for major end item units of products such as ships, a defect that could prevent performance of their tactical function. (MIL-STD 109A)
Defect	Any nonconformance of the unit of product with specified requirements. (MIL-STD 109A)
Examination	An element of inspection consisting of investigation without the use of special laboratory appliances or procedures, of suppliers and services to determine conformance to those specified requirements which can be determined by such investigations. Examination is generally nondestructive and includes, but is not limited to visual, auditory, olfactory, tactile, gustatory, and other investigations; simple physical manipulation; gaging; and measurement. (MIL-STD 109A)
Failure	The inability of a system, sub-system, component, or part to perform its required function. (MIL-STD 721 Navy)
Failure rate	The number of failures per unit time. (MIL-STD 721 Navy)
Inherent reliability	The actual reliability achieved during the design phase. (MIL-STD 721 Navy)
In-process inspection	Inspection which is performed during the manufacturing or repair cycle in an effort to prevent defects from occurring, and to inspect the characteristics and attributes which are not capable of being inspected at final inspection. (MIL-STD 109A)

Inspection	The examination (including testing) of supplies and services (including, when applicable, raw materials, documents, data, components, and intermediate assemblies) to determine whether the supplies and services conform to technical requirements. (MIL-STD 109A)
Inspection record	Recorded data showing the results of an inspection with appropriate identifying information as to the characteristic or class of characteristics inspected. (MIL-STD 109A)
Maintainability	The probability (when maintenance action is initiated under stated conditions) of restoring a system to its specified operational conditions within a specified total downtime. (MIL-STD 721 Navy)
Maintenance	Procedures that can be carried out by the equipment operators for keeping equipment in, and restoring it to, working order. (Accepted military usage.) A defect, other than critical, that could result in failure, or materially reduce the usability of the product for its intended purpose. (MIL-STD 109A)
Mean-time-between-failures (MTBF)	The mean operating time between failures, during which time the item performs as specified. (MIL-STD 721 Navy)
Mean-time-to-failure	The mean operating time to failure, beyond which point the item becomes expendable. (MIL-STD 721 Navy)
Minor defect	A defect that does not materially reduce the usability of the unit or product for its intended purpose; or, is a departure from established standards having no significant bearing on the effective use or operation of the unit. (MIL-STD 109A)
Objective quality evidence	Any statement of fact pertaining to the quality of a product or services based on observations, measurement, or tests which can be fully verified. Evidence must be expressed in terms of specific quality requirements or characteristics. These characteristics are identified in drawings, specifications, and other documents which describe the item, process, or procedure. (MIL-STD 109A)

Operational reliability	The probability that the system will give specified performance for the duration of a mission when used in the manner and for the purpose intended. (MIL-STD 721 Navy)
Probability	The likelihood of occurrence of a particular event. The ratio of the number of ways an event can actually occur to the total number of possibilities. (MIL-STD 721 Navy)
Quality assurance	Quality assurance comprises a planned and systematic pattern of all actions necessary to provide adequate confidence that the product will perform satisfactorily in service (MIL-STD 109A)
Quality control	A management function whereby control of quality of raw or produced material is exercised for the purpose of preventing production of defective material. (MIL-STD 109A)
Quality history	A compilation of inspection or quality control records for an item, or group of items, suitable for evaluation on a time series basis. (MIL-STD 109A)
Random sampling	The procedure used to select items from an inspection lot so that each item in the lot has an equal chance of being included in the sample. (MIL-STD 109A)
Reliability	Probability that a system, sub-system, component, or part will perform its intended function for a specified period of time under stated conditions. (MIL-STD 721 Navy)
Reliability requirement	A level of reliability expressed in an equipment specification as a design requirement (MIL-STD 721 Navy)
Reliability test	Tests designed to measure the level and uniformity of reliability. (MIL-STD 721 Navy)
Sample	One or more units of product selected at random from the material or process represented. (MIL-STD 109A)

Sampling plan	A statement of the sample size or sizes to be used and the associated acceptance and rejection criteria. (MIL-STD 109A)
Surveillance	1) The continuing analysis and evaluation of records, methods, and procedures including the act of verification to assure conformance with technical requirements. 2) A system whereby supplies and equipment in storage are subjected to, but not limited to, cyclic, scheduled, and special inspection and continuous action to assure that material is maintained in a ready-for-issue condition. (MIL-STD 109A)
Testing	An element of inspection which generally denotes the determination by technical means, of the properties or elements of supplies, or components thereof, and involves the application of established scientific principles and procedures. (MIL-STD 109A)
Unit of product	The entity of product inspected in order to determine its classification as defective or non-defective. This may be a single article, a pair, a set, a length, an area, a volume, a component of an end product, or the end product itself. It may or may not be the same as the unit of purchase, supply, production, or shipment. (MIL-STD 109A)
Use reliability	The experienced reliability resulting from in-service maintenance and performance application factors. (Industrial usage.)
Verification	A combination of monitoring actions, inspection, or both, for the purpose of determining compliance of the contractor with the provisions of the contract, and evaluating the effectiveness of his inspection or quality control system. (MIL-STD 109A)

CHAPTER II

HISTORY OF QUALITY ASSURANCE

The history of quality assurance as now perceived in the Navy goes back about 20 years. Examination of World War II and post-war equipment records indicated almost unbelievably low reliability - particularly for electronics equipment. As a result, the Department of Defense conferred with industry and concluded that greater quality assurance could be and must be attained in military equipment.

INITIAL DEPARTMENT OF DEFENSE ACTIONS

The present quality assurance program evolved from a series of Department of Defense directives. The directive which laid much of the groundwork is quoted in part as follows:

> 2. <u>Quality assurance concepts</u>. Quality assurance concept is predicated upon the fact that:
>   a. Responsibility rests upon contractors and producing activities for controlling product quality and for offering to military departments for acceptance only those items or lots of items considered by them to conform to contractual requirements ....
>   b. Responsibility rests with the military departments for determinint that contractual requirements have been complied with prior to the <u>acceptance</u> of the product.
>
> 3. <u>Quality assurance policies</u>. Determination of conformance of products to contract requirements shall be made on the basis of objective evidence of quality and quantity. The Government inspector shall make optimum use of quality data generated by contractors in determining acceptability of supplies to the extent that the contractor's quality data are available and reliable, as determined by government inspection. Such data shall be used to adjust the amount of Government inspection of the product for acceptance purposes to the degree consistent with proper assurance that the supplies accepted conform to the quality requirements established by procurement documents....It must be borne in mind that the Government inspector is responsible for quality and quantity of the products of which he has inspection cognizance.[1]

[1]Department of Defense, Department of Defense Instruction 4155.6, <u>Department of Defense Quality Assurance Concept and Policy</u> (Washington: 14 April 1954).

This was followed in May, 1957 by another Department of Defense directive which defined inspection and verification procedures as follows:

> Factors influencing extent of Government inspection. The extent of Government inspection to verify the supplier's compliance with the quality assurance provisions of the commodity specification and with other technical requirements of the contract shall be adjusted to reflect the following factors:
>
> a) the possible effect of failure of the item on the safety of personnel;
> b) the tactical or strategic importance of the item;
> c) the complexity of the item and the need for high reliability of the item and its components;
> d) the pertinence, completeness and reliability of the supplier's inspection records;
> e) the previous quality history of the supplier's product;
> f) the quantity and technical specialties of available Government inspection manpower;
> g) technical importance of the item; and
> h) the unit cost of the item.
>
> Standard procedures for Government verification inspection. To promote uniformity in Government verification inspection of suppliers' compliance with the quality assurance provisions of specifications and other technical requirements of the contract, the following aspects of verification inspection shall be treated in accordance with the standard procedures contained in the enclosure:
>
> a) review and evaluation of the supplier's inspection procedures;
> b) inspection and calibration of the supplier's gages, measuring and test equipment;
> c) examination of the supplier's inspection records; and
> d) performance of product verification inspection by the Government.[2]

BUREAU OF SHIPS ACTIONS

In 1958, the Navy became vitally interested in the problem when the Bureau of Ships' Inspector General (Rear Admiral Logan McKee) indicated that there was a great need for increased quality and reliability assurance in the work of the Naval Shipyards. A direct result of the McKee Report was the establishment of the Ship Cost Analysis Panel (SCAP). This panel concluded

[2]Department of Defense, Department of Defense Instruction 4155.8. Department of Defense Procurement Inspection Policies and Procedures for Items Covered by Federal and Military Specifications. (Washington: 7 May 1957).

that:

> There is presently no attempt made to relate cost of quality to value of quality. There is no attempt made to determine either the cost or the value of quality. There is, therefore, no real knowledge of whether shipyards are spending far too little or far too much to achieve the quality production they do, or even whether that quality is about right, is too high, or too low. In summary, no real attention has been paid to the whole question of quality control, and in particular to an evaluation of the minimum overall cost of quality.

Significant progress has been made in this area since the first formal directive was issued by the Bureau of Ships in 1960.[3] The quality assurance program, as it relates to organization, policy, definitions, costs and contracts, has been determined and essential implementing directives have been issued. Concepts and philosophies of the quality assurance function have been disseminated. Detailed specifications for specific shipyard processes have been published. Guidelines for such areas as reliability, data feedback, audits, inspection, and motivation have also been covered by Bureau of Ships directives. But the fact remains that this is a relatively new and extremely complex program that will require an extraordinary effort to achieve complete implementation in the organizations concerned with the construction, overhaul, and repair of Naval ships.

[3] Department of the Navy, Bureau of Ships Instruction 4355.14, Quality Assurance Policy. (Washington: 8 November 1960).

CHAPTER III

THE QUALITY ASSURANCE PROGRAM

Quality assurance has been defined as comprising a planned and systematic pattern of all actions necessary to provide adequate confidence that the product will perform satisfactorily in service. In order to be effective, the objectives of a quality assurance program must include:

1) systematic planning, integration and performance of actions necessary for attainment of confidence in product quality;

2) development, implementation, and improvement of work methods and techniques;

3) effective communication of quality requirements and information throughout the organization;

4) achievement of requisite product quality and reliability assurance at a reasonable cost. The costs involved in assuring the quality of the product must be justifiable; and

5) delivery of a reliable product which meets the operational requirements of the user.

This study develops concepts of the management functions required to achieve the above objectives. Along with statements of these concepts are indicated the actions taken, or directed, in the Naval shipyards to implement programs which will assure the quality of the work on the ships delivered to the fleet.

Past practice has been informal, unrecorded, and unsystematic assurance of quality in the shipyard functions of design, procurement, and production. However, as the implications of mistakes become more costly, there is need for predetermined and systematic definition of what will be checked, who will do the checking, what records will be kept, and what the results of analysis of records mean in terms of corrective action.

The Need For A Plan

In order to achieve effective quality assurance, the first and most important step is the development of a formal plan which unites the efforts of the organizations and personnel toward the common goal of adequate quality. In this light, the Chief, Bureau of Ships has directed that the Bureau of Ships and its field activities "shall be responsible for developing an integrated plan for systematic, economical, and constructive assurance of quality through all the operations pertinent to ships and their equipment."[1]

In its broadest terms, the concept of planning is applied to all organizational levels from the manager down to the craftsman on the job and implies a systematic and practical approach to any task intended to be implemented economically and expeditiously. Quality assurance planning should define the pattern of decisions, responses to the decisions, and assurances that the decisions and responses are effective. This will provide a sequential system of steps, actions, or events for achieving the goal of stated quality.

Systematic planning for effective quality assurance must provide answers

[1]Department of the Navy, Bureau of Ships Instruction 4355.14, Quality Assurance Policy (Washington: 8 November 1960).

to the following questions as a minimum:

1) What degree of quality assurance is necessary?

2) What quality assurance measures are required, what is necessary to accomplish these objectives, and what results are anticipated?

3) Where are assurance measures required, where should the work be performed, and where is the required information to be obtained?

4) When and where should assurance efforts be reduced or increased, changed, or eliminated?

5) Who should perform the work, who is responsible for corrective action, and who is performing effectively or ineffectively.

6) How is the work to be performed, how can the process be improved, how can costs be reduced, and how can reliability be improved?

7) What degree of training is required for all persons concerned with quality assurance?

8) Are agreed standards and procedures being complied with and, finally, is the program effective?

Establishing the Quality Assurance Plan

Determining the necessary degree of quality assurance or the level of essentiality of the ship, system, or equipment is the first element to be considered in setting specific objectives of the quality assurance program. The general level of essentiality may be determined by the Chief of Naval Operations' Ship Characteristics Board when promulgating the ship's proposed mission along with the design characteristics. However, standards for detailed determinations of the degree of quality assurance necessary for specific systems and equipment must be decided at the Bureau of Ships/Bureau of Naval Weapons level of design and material responsibility. Final

responsibility for specific communication of essentiality levels rests with the designated activity responsible for developing or approving working and production plans based upon contract specifications and contract plans issued by the Bureau of Ships.

With the level of essentiality set, the elements of the quality assurance program may be detailed. The plan should reflect at least the following:

1) Identification and analysis of each operation which contributes to the quality of the end product.

2) Establishment of job processes, procedures and controls which are necessary to secure the requisite quality.

3) Setting up inspection, test, and audit procedures.

4) Establishment of reliable feedback procedures.

5) Training and qualification of personnel.

6) Procedures for reporting deficiencies and taking corrective action.

Once these broad elements have been decided, they may be broken down into simple procedures - ideally, each consisting of one job done by one man at one place. The responsibility for each task should be defined and the man who is to carry out the task must be informed and understand his responsibilities.

Where possible, master charts of responsibilities and schedules should be prepared to serve both as a plan and as a managerial control. This procedure provides a checklist for inspection and testing and may well reveal where control has been lacking in the past. The plan for audit of critical areas will be facilitated by such a master checklist.

Thus, the planned sequence of quality assurance events should parallel and be integrated with organizational planning to establish the quality assurance prerequisites of design, procurement, production, and inspection events and to allow adequate time in the schedule to take the actions necessary to achieve the requisite quality.

ORGANIZATION FOR QUALITY ASSURANCE

Fundamental to effective planning, production, and control is effective organization. This applied to quality assurance as well as other activities to be carried out by any organization of people. Effective organization defines clear-cut lines of authority and responsibility for planning and carrying out a program.

The Assurance Engineering Office.

Evolving from a similar unit established within the Bureau of Ships in 1960, the present Assurance Engineering Office (Code 609) provides consulting, staff planning and technical advice to the Chief of the Bureau and to the Assistant Chiefs in their areas of cognizance, on matters related to policies, plans, programs, and procedures affecting the value and quality of ships and their material. The Assurance Engineering Office coordinates the guidance and direction of the Naval shipyards in regard to quality assurance matters and monitors the programs set up at these activities. Detailed plans for adapting the policies of the Bureau of Ships must be made within the shipyard organizations.

The Shipyard Quality Assurance Organization.

The first formal requirement for establishment of a quality assurance organization within the Naval shipyards was directed by the Chief, Bureau of Ships in July 1961. Under this organizational policy, the Head of the Quality Assurance Division was responsible to the shipyard Production Officer. A change in the Standard U. S. Naval Shipyard Regulations was directed by the Chief, Bureau of Ships in September 1963 which provided for establishment of the Quality and Reliability Assurance Department responsible directly to

the Shipyard Commander.[2] The associated statement of duties and responsibilities of the Quality and Reliability Assurance Department are contained in Appendix I.

Another change, however, was effected in October 1963 which gave the Shipyard Commander the option to continue the quality assurance function as a division of the Production Department.[3] If this option is exercised, it is then required that the Head of the Quality Assurance Division be assigned an additional billet "on the staff of the Shipyard Commander for purposes of advising on quality assurance matters."

The penultimate decision which placed the quality assurance function at the departmental level of the Naval shipyard hierarchy was based on the need for strengthened organization for assuring quality and reliability and to minimize the probability of organizational conflict relative to continued implementation of the quality assurance program. Given the option, a Shipyard Commander's decision to retain the quality assurance function at the divisional level would appear to deemphasize the role of this function and temper its effectiveness potential.

The quality assurance organizations now established in the Naval shipyards vary in size from about 500 personnel down to less than 100 personnel. The Mare Island and Portsmouth Naval Shipyards, being new construction shipyards for submarines, have the largest quality organizations - which emanated

[2]Department of the Navy, Bureau of Ships Notice 5450.14A Change Transmittal, Change 22 to BUSHIPS INST 5450.14A of 18 March 1958, Standard U. S. Naval Shipyard Regulations. (Washington: 11 September 1963).

[3]Department of the Navy, Bureau of Ships Notice 5450.14A Change Transmittal. Change 23 to BUSHIPS INST 5450.14A of 18 March 1958, Standard U. S. Naval Shipyard Regulations. (Washington: 17 October 1963).

from large Inspection Divisions in being prior to the initiation of the quality assurance program.

Feigenbaum contends that there are two basic principles that sum up the concepts important to organizing for quality control:

> The first principle is that quality is everybody's job in a business.
>
> In defiance of this principle, many businesses over the years have attempted to centralize their company quality responsibility by organizing a function whose job has been handsomely described as "responsibility for all factors affecting product quality." These experiments had a life span of as long as 6 to 9 months, that is, when the job incumbent had the advantage of a strong stomach, a rhinoceros hide, and a well-spent sober boyhood. Others not similarly endowed did not last the 6 months.
>
> The simple fact of the matter is that the marketing man can best evaluate customer's quality preferences. The design engineer is the only man who can effectively establish specification quality levels. The shop supervisor is the individual who can best concentrate on the building of quality.
>
> Total-quality-control programs thus require, as an initial step, top management's reemphasis of the respective quality responsibilities and accountabilities of all company employees in new-design control, in incoming-material control, in product control, and in special process studies.
>
> The second principle of total-quality-control organization is a corollary to this first one: because quality is everybody's job in a business, it may become nobody's job. Thus, the second step required in total quality programs becomes clear. Top management must recognize that the many individual responsibilities for quality will be exercised most effectively when they are buttressed and serviced by a well-organized, genuinely modern management function whose only area of specialization is product quality, whose only area of operation is in the quality-control jobs, and whose only responsibilities are to be sure that the products shipped are right--and at the right quality cost.
>
> The two basic responsibilities of this total-quality-control function may be formally stated as first, to provide quality assurance for the business's products, and second, to assist in assuring optimum quality costs for those products.[4]

[4] A. V. Feigenbaum, Total Quality Control (New York: McGraw-Hill Book Company, Inc., 1961), p. 49, 50.

DESIGN ASPECTS OF QUALITY ASSURANCE

Design is a decision-making process which plays a most important part in the quality of the end product. The multitudinous decisions of design functions are represented in their output of detailed construction plans with bills of material, identification and inspection plans, tests and trial forms, technical manuals, lists of repair parts, etc. This dissemination of decisions is wholly as important as the decisions themselves. The implementation of these decisions in actual construction or over-haul, operation, and maintenance will be effective only if these decisions are transmitted clearly, definitively, and completely.

Design Functions.

Basically, it is design's task to develop "paper" details which satisfy the contract design. The Bureau of Ships' responsibility is to ensure that the contract design satisfies the assigned characteristics just as it is the Ship's Characteristics Board's responsibility to see that the characteristics satisfy the intended mission of the ship determined by the Chief of Naval Operations. Completing this loop, it is the right and responsibility of design to bring to the Bureau's attention any deficiencies in the contract design. This represents a quality assurance check on the contract design just as the development of the contract design is a quality assurance check on the characteristics, etc.

The critical factors or level of essentiality of the particular product or ship must be recognized within the quality assurance system. Necessarily, the first to recognize the critical characteristics is the ship or equipment designer who must identify and communicate these parameters and establish the criteria for procurement, production, inspection and test.

The quality of design is dependent upon the capability and experience of the designer, the amount of deviation from past practices, and the degree of pushing of the state-of-the-art. Assurance of design quality is achieved through the use of models and mockups, design checks and reviews, engineering checks and reviews of completed plans, design review and approval by other agencies, preinstallation tests of new design hardware, etc.

The real proof of design quality, however, comes in the actual procurement, manufacturing, construction and inspection and test processes - and finally in the actual operation of the end product. These phases involve quality control to ensure that the product is built and tested to the design outputs. This is an important quality assurance check on design. Any deficiencies in the product not attributable to lack of quality control during production must be fed back to design for immediate correction as well as for development of basic know-how on which future design decisions will be made.

It is design's job to select material, fabrication methods, inspection techniques and tests to achieve a desired end result at minimum cost, assuming good workmanship. So, in addition to feedback of design defects, it is also essential that they be appraised of new materials, new manufacturing processes and new inspection techniques that are now available and can do the job as well or better or at a lesser expense of labor, materials, or time or which improves the chances of success. For examples, Dallinger and Goode indicated that a review of all non-destructive test acceptance standards is needed to:

(a) Insure that the cost for obtaining each quality level specified can be justified by the increase in reliability and the reduction in product down time that results from use of the specified standard.

(b) Insure that the state of the art can support the requirements for manufacturing and testing.

(c) Insure they are sufficiently definitive and technically accurate for the end item use.

(d) Insure the standard is capable of uniform interpretation by various unrelated activities including INSMATS.[5]

Planning and Estimating Tasks.

Following design action, the Planning and Estimating Division of the shipyard must develop job orders which clearly delineate the way the job is to be done to meet specifications, including those prescribing quality. The job orders must reference the applicable process instructions and methods standards and define the inspections and tests to be performed and the quality assurance records to be kept. Procurement documents must result in material of the quality required by specifications. Conflict between plans, job orders, and specifications should be referred back to design for resolution.

[5] J. F. Dallinger and O. R. Goode, "Quality Control in Shipbuilding," Naval Engineers Journal, June 1964, p. 406.

LEVELS OF ESSENTIALITY

Failure of piping exposed to sea pressure has presented a significant hazard to more than one submerged submarine and is generally believed to have been the cause of the loss of THRESHER in April 1963. Such critical factors as represented by this example must be recognized within the quality assurance system.

<u>The Three Levels of Essentiality</u>.

Having recognized this problem in 1961, the Bureau of Ships established three levels of essentiality for piping systems which reflect their relative significance in terms of the ship's mission and safety. Initially, these levels were established for use in assuring accurate material identification of piping and verification of correct installations through checks of identification markings against specifications. The levels of essentiality have been applied to fabrication processes, inspection, the actions of supervision, training, and audit inspection of piping systems.

a. Level I encompasses those piping systems in which:
   (1) Stress levels, such as arise from temperature, pressure, vibration, or shock, create a high probability of failure if incorrect materials are used and -
   (2) Failures would significantly and directly for combatant ships, (a) reduce the ships primary combat effectiveness, and/or (b) jeopardize the safety of ship or numbers of personnel, particularly through release of stored energy, toxic and/or hazardous fluids/vapors...

b. Level II encompasses those systems in which:
   (1) Stress levels, such as arise from temperature, pressure, vibration, or shock, create a high probability of failure if incorrect materials are used and -
   (2) Failure would (a) for combatant ships, decrease the ability to sustain the intended efficiency, accuracy and reliability of systems essential to their combat effectiveness (b) for auxiliary ships, significantly and directly reduce their primary mission effectiveness.

c. Level III encompasses those piping systems in which failure due to incorrect material is unlikely or will have little or no effect on the performance of the ship's combat or mission

effectiveness.[6]

Level I represents those systems for which maximum confidence is required and derived from as firm a base of factual information as is possible. It involves special designation of materials on all documentation, 100% verification by physical or chemical tests of the correctness of material and its identification by markings during fabrication and installation, specified process and process control, training and qualification of personnel involved, and periodic audits. In summary, Level I requires a complete and documented quality assurance effort.

Level II systems require control similar to that for Level I except that less verification of material properties is appropriate provided there is confidence in the vendor, although the shipyard is still responsible for the correctness of subcontracted material.

Level III applies to systems which utilize material whose identity will generally be assumed correct unless there are indications to the contrary or no identification markings exist. Inexpensive checks are recommended to assure that the material is correct in those cases where errors in material would be expensive to correct.

Modified Policy on Levels of Essentiality.

In September 1964, the Bureau of Ships modified its policy on levels of essentiality by stating:

> The shipbuilding may classify piping systems and designate parts as either Level I or Level III. If only these two levels are used, those systems and parts formerly designated as Level II shall be upgraded to meet Level I requirements.[7]

[6] Department of the Navy, Bureau of Ships Instruction 4410.17, Material Identification System (Part I: Piping Materials) (Washington: 22 June 1961).

[7] Department of the Navy, Bureau of Ships letter serial 609.1-275, Bureau of Ships Instruction 4410.17, Material Identification system: Clarification of Application (Washington: 21 September 1964).

This modified policy has resulted in confusion in the application of levels of essentiality in the shipyards. Some shipyards apply only two levels where others use the original three. One shipyard is reported to have gone so far as to adopt a policy of Level I material and "all-other-material." One might question what that shipyard does when it comes across a plan indicating Level II material is to be used. The problems come to light when there is an exchange of plans, procurement specifications, and material between the shipyards. All personnel concerned must be made aware of these differences to reduce the impact of the confusion factor and to prevent errors in material procurement, inspection, and application.

Even with the guidelines provided relative to piping systems, there is not uniformity among the shipyards in the assignment of essentiality levels to these systems. Less guidance has been provided in the areas of machinery, electrical systems, hull machinery, and hull appurtenances.

FEEDBACK

Feedback is the information system which is an essential part of the quality assurance program. Feedback indicates the quality or reliability of an equipment or system at the time of receipt of the material from another source, at the time of inspection or test after installation, or under daily operation in the fleet.

Ideally, the feedback system represents a closed loop intelligence system that links together the various organizational components of the total quality assurance system. Through this loop, specific quality results may be measured, analyzed and then fed back for use in replanning. This is extremely important since feedback provides the basis for improvement of the design, procurement, production, inspection, and audit phases of the quality assurance program.

To be effective, the information system must be complete. Unless areas of unsatisfactory quality are reported to the persons responsible for the state of quality of the product, it can be anticipated that necessary improvements will not be effected in current and future actions relative to that product or those similar in nature to it.

Periodic review of the quality feedback system is necessary to keep it current in meeting the changing needs of the organizations concerned. Besides identifying new organizational components that require certain quality information, attention must be given to eliminating distributions whereby no useful purpose is currently being served.

Currently, there are four formal feedback systems which provide failure information on equipment and systems in the fleet.

1) Casualty Reports (CASREPTS) are reports of significant material casualties or failures submitted by the Commanding Officer (or Officer-in-Charge) of a ship or station. Those casualties which are serious enough to affect the ability of the command to carry out its mission are reported by Naval message. Less significant casualties are reported by speedletter. Copies of these CASREPTS are forwarded to the material bureau concerned for collection, classification, review, and analysis by designated offices or codes. These codes are responsible for coordinating corrective action where the bureau is directly involved. These codes also distribute failure data to the responsible Navy industrial activity or inspection office (in the case of contractor material) for corrective actions in the event that poor workmanship or lack of adequate quality assurance is indicated.

2) Form NAVSHIPS 3621 is used to report failures of shipboard mechanical, electrical, and hull equipment which are under the cognizance of the Bureau of Ships.[8] This failure report is required to be submitted after repairs are made and generally provides sufficient detail for analysis and decision as to the soundness of design and quality assurance.

3) Form BuShips 10550-1 is used to report failures of selected electronics equipment under the cognizance of the Bureau of Ships.[9] Associated with this is Form BuShips 10550.14 which is used to report accurate

[8]Department of the Navy, Bureau of Ships Instruction 9000.13A, Failures of Bureau of Ships Mechanical, Electrical, and Hull Equipment, Reporting of (Form NAVSHIPS 3621) (Washington: 24 November 1959).

[9]Department of the Navy, Bureau of Ships Instruction 10550.73, Revised Electronic Failure Reporting System; Implementation of (Washington: 28 June 1961).

operational time based data for reliability, maintainability, and availability figures of merit and for failure and replacement rate calculations of the selected electronics equipment.[10]

4) The Standard Navy Maintenance Management System (SNMMS) is currently being implemented in the fleet under the direct sponsorship of the Chief of Naval Operations and has as its objective "the improvement of the material readiness of the fleet through improved management of maintenance and material functions."[11] With a goal for completion in 1966, this system is expected to provide the basis for uniform planned maintenance of fleet equipment, the collection of maintenance data in a form that will facilitate machine processing, and the establishment of an activity capable of processing and analyzing the maintenance information received. The analyzed data will then be utilized in providing feedback and responsible assistance to the operating forces. System reliability, failure rates based on operating time and inspection periods, and other maintenance and material matters will be available in the storage of the data processing and analysis system.

At the shipyard level, the Bureau of Ships has set forth the requirements for inspection and audit of the effectiveness of the control of quality.[12] Defect reports which result are fed into the in-yard feedback system for the purpose of assuring correction of deficiencies found and to

[10] Ibid.

[11] Department of the Navy, Office of the Chief of Naval Operations Instruction 4700.16A. Standard Navy Maintenance Management System (Washington: 1 August 1963).

[12] Department of the Navy, Bureau of Ships Instruction 4355.20, Quality Assurance Program; Inspection Responsibilities Under (Washington: 12 March 1962).

initiate actions to prevent unnecessary recurrence.

The implications of the footnoted directives is that a system of casualty, failure, and defect reporting has been established including assignment of responsibility. If the bureaus and shipyards are to provide reliable corrective action to the fleet, all reporting activities in turn must provide accurate, complete, and timely reports. Except for serious casualties, reports of material failures and defects tend to be sporadic in many cases. This can be attributed to past instances where no positive corrective action was ever taken on reports of significant failures. But, in turn, those reports that are made must be delivered to the individuals cognizant over quality in each case. And, finally, after intelligent analysis and decision making, these individuals must initiate and follow-up preventive actions. Otherwise, the purpose of the systematic feedback system is defeated.

No basic materials originate in the shipyard. All materials, raw or finished, must be obtained from outside sources. Approximately 50 percent of an average ship is fabricated from raw materials and 50 percent is built from finished components. The assurance of quality of these materials is vital to the overall quality assurance program in the shipyard. The quality of the incoming material depends upon the adequacy of the procurement documents and the degree of inspection used to confirm vendor compliance with these documents.

Procurement Documents.

Procurement documents for material should contain the following information:

1) technical characteristics;
2) applicable Government specifications;
3) process standards;
4) special specification requirements; and
5) quality assurance provisions including the level of confidence required.

Technical and quality assurance review of procurement documents should include such points as the level of essentiality, clear definition of tolerances and other acceptance standards, inspection points and tests, process approvals, personnel qualification, material certification and markings, extent of source inspection, and the validity of the referenced documents. Incorporation of these requirements will eliminate many potential causes of rejections when the material is received. In some cases, it is possible to prepare a separate quality assurance specification that can be included in

all applicable purchase orders. The use of such a quality assurance specification will condense the many varied documents that have to be referenced and make it easier for the vendor's quality assurance organization to ensure that all requirements are complied with.

<u>Vendor Quality Assurance Programs.</u>

Where the material being procured is of Level I essentiality, it is important that a pre-award survey of the vendor be made by quality assurance personnel to ensure that the vendor can, in fact, meet the requirements of the procurement document. The pre-award survey is a review of the vendor's overall quality control procedures and performance. Such a survey also includes special requirements of radiography, heat treating, and laboratory facilities that may be peculiar to the particular procurement.

Military Specification MIL-Q-9858A, "Quality Control System Requirements," where included as a requirement in the procurement document, requires the vendor to establish a quality assurance program to assure compliance with the requirements of the procurement. Military Specification MIL-I-45208A, "Inspection System Requirement," establishes minimum requirements for contractor' inspections and tests necessary to substantiate product conformance to specifications. This specification is used for contracts where the product complexity does not necessitate the application of MIL-Q-9858A. NAVEXOS P-1034, "Manual for Source Inspection and Administration of Navy Procurement," also specifies contractual requirements for establishment of a formal inspection or quality control system. These documents also provide methods for evaluating the effectiveness of the vendor's quality assurance system.

The Inspector of Naval Material and the Supervisor of Shipbuilding organizations are the Government activities which normally carry out the pre-award survey, inspection, and verification functions where source

inspection is necessary. The Supervisor of Shipbuilding carries out these functions in the cases of material orders from private shipbuilding contractors and the Inspector of Naval Material does so for material and equipment vendors.

Since, generally, the source inspection is carried out by a Government activity other than the shipyard, it is doubly important that the procurement document be clear and complete. Where special processes or techniques are involved, such as the welding of HY-80 steel, it may be necessary to arrange for Inspector of Naval Material inspectors to attend special schools. In other cases, it may be necessary for shipyard quality assurance personnel to visit the Inspector of Naval Material to ensure full understanding of the intent of the requirements of the procurement and the application of the end product. In all instances of critical material, there should be an open line of communication to preclude misunderstanding on the part of either the vendor or the source inspector.

Material Receipt Inspection.

In addition to the material that the shipyard purchases, the shipyard receives material purchased by the Bureau of Ships, the various supply systems within the Department of Defense, and other private and Naval shipyards. Hundreds of vendors are involved. The material is of varying complexity and criticality. Inspection must be performed on all incoming material to ensure that it conforms with the purchase order, or the shipment order when forwarded by other Government activities. The amount of inspection required should be based on the level of essentiality, the complexity of the item, or the need for high reliability.

Re-inspection of nonessential material is costly and unnecessary. Establishing sampling plans is a recognized means of eliminating 100 percent inspection of materials in large quantities. But, the need for high confidence for highly essential applications, and the need to minimize the probability of incurring expensive ripout, repair, and replacement of defective items may demand 100 percent inspection of certain materials.

By the use of modern metal identification equipment, it is relatively easy to confirm the basic identity of all materials. Proper inspection permits correlation between the actual material and the documentation submitted to support the quality requirements. Improved non-destructive test equipment such as magnetic particle and fluorescent penetrant can provide adequate assurance that no significantly defective material will be accepted. Use of written procedures for such inspection, together with written records, will increase the effectiveness of the inspection and provide a means of confirming the quality at a later date.

When material is found that does not conform to specifications or plans, the nature of the deficiency should be evaluated to determine whether the material should be returned to the vendor as "non-conforming" material. Some deficiencies are minor in nature and technical evaluation can provide a basis for accepting non-conforming material with the assurance that the basic quality of the completed ship will not be lowered. But, it is the vendor's responsibility to deliver material which fully conforms to the applicable specifications. Basic quality assurance policy demands positive refusal to accept departures from those specifications.

Identification Markings.

Essential to material identification and control is that of proper identification markings. The Bureau of Ships has provided guidelines for marking of

material by vendors, and by the shipyards during receipt inspection.[13] The requirements for Levels I and II material are permanent markings indicating the essentiality level, material composition, specification, lot or serial number, manufacturer's symbol, date of receipt inspection, and the number assigned to the receipt inspector. These markings are intended to permit traceability from the material back to the records - objective quality evidence. Optional markings may be added by the shipyard to assure proper use or application of the material. Stamps, tags, etc., are permitted for identification marking of Level III material.

[13]Department of the Navy, Bureau of Ships letter serial 609.1-275, Bureau of Ships Instruction 4410.17, Material Identification System: Clarification of Application. (Washington: 21 September 1964).

INSPECTION AND TEST

Inspection has been defined as "the examination (including testing) of supplies and services (including, when applicable, raw materials, documents, data, components, and intermediate assemblies) to determine whether the supplies and services conform to technical requirements. The purpose of an inspection system in the Naval shipyard is to provide uniform, systematic, and planned inspections during the various manufacturing processes and for acceptance of completed work.

The Inspection System.

Development of a suitable inspection system should provide for the acceptance of all conforming work or material and rejection where non-conforming, should encourage the individual to improve the quality of his work, should be easy to administer and economical in cost, and should not delay production or impose an unreasonable and costly burden of materials handling, inventory accumulation, etc.

Written procedures are essential to effective quality assurance inspection and should include:

1) designation of the inspector(s) responsible;
2) the actual inspections to be conducted;
3) the records to be maintained as evidence of inspection;
4) the acceptance standards to be used;
5) markings to identify accepted work; and
6) the equipment to be used for conducting the inspection and the personnel qualification and equipment calibration requirements.

The quality assurance organization must first ensure that the inspector is qualified to conduct his assigned inspection procedures. For example, to qualify an inspector for ultrasonic inspection of silver-brazed piping joints, the man must take a special training course and then pass a rigid qualification test just as the welder must be trained and qualified to accomplish the silver-brazing operation. The necessary test equipment, properly calibrated by one of the designated laboratories or against a local reference standard, must be available to the inspector. Written procedures will provide the inspector with the standards of acceptance, the markings required to identify accepted work, and the records of inspection that are to be maintained. Use of check-off lists will help to ensure that all required inspections have been made.

Inspections must be coordinated with the production schedule to eliminate unnecessary delays. Though 100 percent inspection is required for Level I items, statistical sampling may be suitable in other cases. Over-inspecting will only delay production and add unnecessary costs to both the production and inspection efforts. However, inspection should not be eliminated as an expedient to meeting production schedules.

Periodic audits will assure that the inspector is qualified, inspections are accurate, the proper test equipment is used, all necessary inspections are conducted, and the required records of inspection are accurate and complete.

QUALITY ASSURANCE AUDITS

A major function essential to confidence in the assurance of quality is the audit. The usual dictionary definition of the term is "a formal or official examination and verification of accounts." As previously defined in this paper, audit is "the analysis and evaluation of procedures, methods, and records to determine compliance with existing requirements." In order to be an effective tool of quality assurance, the audit process must be a formal, planned, and systematic analysis and verification of quality by gathering objective evidence of conformance to established standards.

Planned Audits.

The Bureau of Ships has identified quality assurance audits to be made as:

1) those audits necessary to know what the variabilities are that cause the distribution of quality in design, procurement, and production;

2) those audits of the effectiveness of a systematically planned action pattern which will assure these variables are identified, defined, and controlled;

3) those audits necessary to determine weak links in the quality control exercised over the design, manufacture, test, and use of the product;

4) those audits necessary to determine excessive specification requirements as related to end use and product function. Here, the Quality/Realiability Assurance Engineer starts to determine the levels of essentiality, recommend simplification of the processes, and establish the objective quality evidence needed to evaluate compliance to required standards; and

5) those audits necessary to determine (a) the extent and accuracy of inspections made either by an inspector or by other groups, (b) the purpose of the inspections made, (c) the extent and accuracy of inspection of the work by the worker, (d) the extent of the inspection of the work by supervisor of the workers who produced the job, and (e) the adequacy of inspection records and inspection processes used.[14]

[14]Department of the Navy, Bureau of Ships, Quality/Reliability Assurance Training Program Notebook (Prepared by General Dynamics, Electric Boat Division, Groton, Connecticut; October 1962). pp. 3-18-4, 3-18-5.

The Assurance Engineering Office of the Bureau of Ships now conducts audits of each private and Naval shipyard building Naval ships, with particular emphasis on submarine work. In addition, the shipyards have been directed to establish audit teams and to conduct certain audits of their own quality systems. Audits are currently made of the following specific areas:

1. Material identification and control;
2. Non-destructive testing (NDT)
3. Fabrication of HY-80 steel;
4. Pipe welding;
5. Silver brazing;
6. Shipyard inspection system;
7. Waivers and rip-out procedures; and
8. Standardization and Calibration of inspection and measuring instruments.

It is noted the current audit program of the Bureau of Ships does not attempt to measure the overall effectiveness of the quality assurance plan at a particular Naval shipyard. However, the areas which the audits now concentrate on are those with the greatest payoff for assurance of quality in the particular submarine which will soon be operating in an environment of extreme sea pressure on its hull boundaries.

Planned audits determine the capability of the shipyards to perform in accordance with the specification requirements, verify the degree of compliance with the requirements, and show what level of confidence may be expected in the completed ship or product. Such evaluations provide feedback information on specification and design deficiencies, training needs, communication problems, manpower and skill needs, deficiencies in systematic planning, and deficiencies in production and inspection equipments. The

final phase of the audit function is the follow-up to ensure that corrective action is taken in those areas where deficiencies were evident.

Certification for Sea Trials.

In 1964, certification for sea trials was made a requirement for all new submarines. This certification defines the actions and responsibilities required to assure that submarines under-going construction have the required hull integrity and work completeness to assure a safe and reliable conduct of the sea trials. This requirement has reinforced the need for a continuous, planned, and systematic quality assurance effort in that the final certification is dependent not only upon the thoroughness and adequacy of the final audit effort but upon the completeness and effectiveness of the quality assurance effort throughout the entire construction period.

COST OF QUALITY ASSURANCE

A natural and frequently expressed reaction to quality assurance is that it increases costs. Without doubt, costs will be increased in those industrial activities where quality control is not normally practiced. This expectation of increased costs applies equally well to the introduction of any management control system where none had previously existed. But, to bring quality assurance costs into their proper perspective, it might be recognized that the costs are devoted to knowing what level of quality is actually attained as opposed to assuming the state of quality. One must then compare the costs of achieving a specified level of quality with the total costs when the requisite quality is not achieved.

Cost of Quality Versus Need.

Rework of preventable material failures is expensive and such costs are measurable. However, we cannot always measure such costs as loss of combat effectiveness, interference with operational readiness while undergoing shipyard or tender repair, or the effect on the logistics system. It is unreasonable to assume that a dollar figure could be placed on the failure which resulted in the loss of THRESHER in April 1963. The costs of building, outfitting, and overhauling THRESHER can be expressed and we can also measure the Navy's investment in the men. But we cannot put a price tag on the lives of these men nor can we quantify the costs of possible loss of morale or confidence within the whole of the submarine fleet as a result of this tragedy.

The basic decision of how much quality is needed will generally be based upon the level of essentiality or the critical characteristics of the

product. In turn, the cost of assuring quality and reliability is dependent upon the level of essentiality of the product. It would be rather absurd to require the same level of quality for a ship's ice cream maker as for a main propulsion engine. In short, the necessity for a high degree of quality and reliability assurance in critical systems or equipment may far outweigh the costs of assuring their quality.

The costs of assurance of quality should be weighed against the costs of repairs should failure occur,where such costs are tangible. Statistics available in most shipyards will provide average costs of repairs to particular shipboard equipment and systems. Failure or defect costs which must be considered include rejected and scrapped material, repair and rework, corrections of deficiencies after delivery, and design development or error corrections.

Isolation of costs involved in achieving assurance of requisite quality to prevent failures and need for repair or rework may be a more difficult task. At the minimum, gross measures of such costs can and should be determined and included in the process of deciding the amount and types of inspection, tests, and documentation to be applied. The cost of assuring quality should be commensurate with the value of the quality level achieved. Cost effectiveness must be applied to quality assurance just as it is for other decision making processes in the Navy.

Another factor to be considered is that when a quality-cost program is first initiated, it will probably be found that the dollars spent in preventive effort will save many more dollars in failure costs. However, as the program progresses and the most costly causes of failure are brought under control, further preventive effort may not pay off at as high a ratio.

In time, the curve will flatten out to the point that the same level of preventive effort can no longer be justified. Complete reporting and analysis of quality costs will help in determining when the quality-cost elements are in optimum balance.

Professional societies and major industry indicate that perhaps 8 to 15 percent of the total costs of their operations may be involved in assuring delivery of high quality and reliable products to their customers. In the aerospace industries, this cost has occasionally risen to 75 percent of the total product cost in order to secure adequate assurance of reliability. In the submarine construction area of the shipbuilding industry, such costs approach 10 percent and may rise with increasingly stringent quality/reliability assurance requirements being included in new shipbuilding contracts.

HUMAN FACTORS

People represent the most important factor responsible for the success or failure of any quality assurance program. Nearly the total organization must share the burden of quality. This philosophy can be implemented only by commencing with management for communication and understanding throughout the organization. Accordingly, the first individuals within the organization to understand both the need for quality assurance and its implications must be management.

Motivation and Training.

It is the responsibility of management to take steps to create an environment and motivation conducive to achieving quality. "Human experience is full of proofs that the state of mind is of great importance in achieving an objective...quality mindedness is no exception...change of state of mind always involves indoctrination."[15] Simply telling supervisors, designers, purchasers, mechanics, inspectors, etc., that they should strive for quality because quality is good or because the fleet demands quality does not provide the motivational effect needed. Through a training and/or indoctrination program, the individual will learn why quality assurance is really necessary, what part he plays in the quality assurance chain, what results when he does not achieve the standards required of him and, most important, he will learn how to achieve or better the standards.

The performance of personnel is variable. This variability is the result of many personal variables such as motivation, intelligence, differences in education and training, attitudes, morale, basic aptitudes, interests,

[15]Ibid., p. 3-19-9.

values, etc. The purpose of training is to develop needed attitudes, knowledge, and skills which will reduce the level of performance variation.

Responsibility for training falls on all levels of management. A training organization, as such, does not relieve line personnel of their responsibilities for determining training needs as well as planning and executing those activities necessary for supplying these needs.

Training is generally considered a tool for teaching skills. In the quality assurance program, training must also be directed toward motivating the individual to reach high quality goals at all times. However, the source of motivation must not be ceased upon doling out a certificate of completion of training. There must be an ongoing program to remind the individual of the need for quality. Quality workmanship or performance should be recognized and rewarded. Every effort should be made to exploit the natural aspiration of an individual to do a job well. Group influence on the individual must not be neglected.

Zero Defects Program

"Zero Defects" is a motivation program aimed at making members of the military and industrial complex more quality conscious and dedicated to the goal of doing every job right the first time. The Bureau of Ships initiated a Zero Defects Program in January 1965 for application in the shipyards and other manufacturing activities.[16] The overall objective is to motivate the individual to do the job right the first time. To this end, the individual will be made aware of the importance of his work to the overall success of

[16] Department of the Navy, Bureau of Ships Instruction 4120.15, "Pride" (Zero Defects) Program (Washington: 18 January 1965).

the Navy mission. He will also be informed of the relationship of quality workmanship to his job security.

Individual and group recognition will be provided for good workmanship, and a spirit of teamwork will be developed among individuals and groups to promote good work. The success of the program is to be measured in terms of reduced cost and improved quality of products.

The zero defects goal is seemingly impossible. However, many industrial organizations have introduced the basic concepts of the zero defects program under various names and significant results have been achieved. The theme of this program is prevention of defects rather than detection of defects. Doing the job right in the first place would result in tremendous savings of time and resources if scrap, rework, and modification were eliminated. Savings, cost reduction, and cost avoidances resulting from zero defects programs will be reported as reduced operating costs under the Cost Reduction Program of the Department of Defense.

The error-cause elimination feature of the zero defects program is vital to its success. Both the design engineer and the man on the production line have a part to play in identifying and eliminating errors. The engineer must make sure that the requirements that he establishes are realistic. Producibility and performance in accordance with the needs of the user or the level of essentiality must be provided, without demanding something that is more sophisticated, more costly, and more difficult to build than necessary. Any deviation from this realistic approach can only result in increasing the probability of defects and the cost of rework or scrap.

The mechanic, welder, or electrician carrying out the production tasks are expected to respond quickly and effectively to error-cause elimination

when his recommendations are sought on ways to turn out a consistently defect-free product. Not only will the recommendations be helpful but the spirit of cooperation and working together to produce a quality and economical product will be motivating forces.

Once in full operation, the zero defects program is intended to be sustained by periodic review with, and motivation of, all personnel. Accomplishments in terms of defect trends, dollars saved, and schedules met will be published and discussed in group meetings. The individual must be made to feel that these are, in part, his accomplishments, that he plays a part in the future of the shipyard, and that its future is important to him.

The zero defects program will re-emphasize pride in performance and pride in product. Being slanted toward the individual, no one is to be excluded since quality of the end product is everyone's business. Success of the program must stem from its acceptance by the most basic element of the organization - the individual. The aim is to motivate by challenging, educating, and producing a sense of identification with the product produced.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The modern, complex, and high performance Naval ships being delivered to the fleet today by our shipyards can be expected to operate under highly adverse conditions. It is necessary to know beforehand that they will perform, or even survive, prior to subjecting them to such as the extreme sea pressure on the hull boundaries of the modern submarine at design depth. Our ships may have to endure such unusual hardships as typhoons and collisions. It must be remembered that, though being designed and built in peacetime, the ships in the fleet represent preparedness for war. In the event of war, they must be able to carry out their missions in the face of long periods of steaming at high speed, bomb hits and near misses, depth charge shock, and the other hazards of battle.

It is necessary to instill confidence within the fleet that the ships being built - and overhauled and repaired - in our shipyards will perform safely and reliably. Objective evidence of quality is required in critical areas. The quality assurance program instituted by the Bureau of Ships in November 1960 is intended to provide the necessary assurance that the standards of quality are being met. Significant progress has been achieved, but the fact remains that this is a new and complex program that is not uniformly implemented in the organizations concerned with the design, construction, overhaul, and repair of Naval ships.

Quality is considered to be that which is established by standard procedures and methods to result in a physical product. Quality assurance, on the other hand, is comprised of all the actions necessary to provide adequate confidence that the product will perform operationally as intended.

The first step in the quality assurance program is to develop a formal plan which unites the efforts of the organizations and personnel toward the common goal of adequate quality. The plan should be based on what must be done, where it must be done, who will do it, who will check that it is done right, and how personnel will be trained and motivated to carry the plan out. Master charts of responsibilities and schedules will serve both as a plan and as a tool of managerial control. The plan should provide for audits to show whether or not it is being carried out.

The planned sequence of quality assurance events should be integrated with organizational planning to establish the authority and responsibility centers for the design, procurement, production, and inspection actions.

The Bureau of Ships has given the Shipyard Commanders the option of establishing the primary quality assurance organization at either the department level or as a division of the Production Department. Appendix I lists the duties and responsibilities of the Quality Assurance Department. Where established at the division level, the Quality Assurance Officer has line responsibility to the Production Officer and staff responsibility to the Shipyard Commander. Both systems of organization exist in the shipyard family, as well as other variations.

Textbook principles of organization would demand placing the quality assurance function at the department level reporting to the Shipyard Commander. This was also the opinion of the court which inquired into the circumstances of the loss of THRESHER.[1] However, it is necessary to face up to the fact

[1] U. S. Congress, Joint Committee on Atomic Energy, Loss of the U.S.S. "THRESHER", Hearings before the Joint Committee on Atomic Energy, 88th Congress, 1st and 2nd Sessions, June 26, 27, July 23, 1963, and July 1, 1964 (Washington: Government Printing Office, 1965), p. 153.

that the Naval shipyards are under the management of Naval officers with dual positions in the shipyard hierarchy in terms of rank and organizational position. A Navy Commander may be the most effective on a daily basis in his interactions with the Planning and Supply Departments (headed by Captains) where he has been assigned as head of the Quality Assurance Division and has gained the full support of the Production Officer (a senior Captain). The personalities of the officers concerned could be the deciding factor as to the most effective organization in a particular shipyard at a particular time. But, what happens when the policy of rotation results in different officers in these positions?

Where the demand for quality emanates from the Shipyard Commander, a Navy Commander who is qualified in quality assurance should be able to exercise the necessary influence to be effective as head of the Quality Assurance Department. This would remove the Production Officer from the position of deciding whether to waive quality requirements in favor of completing ships on schedule. The problem is then in the hands of the Shipyard Commander where it properly belongs.

Now that the amount of submarine construction is starting to decline at the Mare Island and Portsmouth Naval Shipyards, it would seem that the numbers of quality assurance personnel should be reduced in some proportion to the declining workload. At least, this is a proper period of time for the management of these shipyards to sit back and objectively reevaluate their Quality Assurance Divisions in terms of objectives, effectiveness and efficiency, span of control of quality related functions, and numbers of personnel required to do the job right. Production, design or supply functions which may have been transferred to the Quality Assurance Division in the face of dynamic

expansion and the urgent need for quality, as was further emphasized by the loss of THRESHER, should be returned to line supervision. Personnel should be reduced in the areas where the need can no longer be adequately justified. It is understood that a study of this general nature has been, or is being, undertaken at Portsmouth Naval Shipyard. Analysis of the Portsmouth study may assist the remaining shipyards in their own review of objectives and plans to meet the goals of quality assurance.

The basic job of design is to make and disseminate decisions that will result in the desired end product characteristics at reasonable cost. In order to make intelligent decisions, the designer must have the necessary experience and training. He must be kept abreast of the state-of-the-art developments in materials, manufacturing processes, and inspection techniques. He must be able to identify the critical characteristics of the particular item to establish the criteria for its procurement, job orders, manufacture, inspection and test. The designer also needs feedback from inspection and from the fleet for analysis of defects and failures to improve his design decisions in the future.

The assurance of quality in the design phase is achieved through the use of models and mockups, by design checks and review, and by preproduction or preinstallation tests. Design review is one of the most powerful tools available to quality assurance management to assure that reliability, level of essentiality, and other important design factors are considered early in the design. Planned and formal quality assurance review and audits of design are not yet being conducted in some shipyards.

Design's definition of the product in terms of plans, specifications, and inspections must be clear and complete so that procurement, production, and inspection personnel are operating from the same standards. In order to establish the critical parameters of the item, design must first determine:

1) What would be the result of failure of the item?
2) What are the minimum requirements for a reliable design?
3) How likely is the item to fail under various alternatives of design and safety factors.
4) Is there redundnacy?
5) How much will inspection cost? An alternative to 100% inspection may be overdesign.

In the process of deciding the answers to the above questions, the designer must establish the level of essentiality of the item relative to stress levels, the effect of failure on mission or combat effectiveness, and the effect on safety of the ship and its personnel.

Level I represents those systems for which maximum confidence is required. Such confidence is to be derived from as firm a base of factual information as is practicable. In short, Level I requires a complete, documented, and verifiable quality assurance effort. Level II requires less effort in verification of materials while Level III requires a minimum of checks and assurance.

The Bureau of Ships appears to have created confusion when they provided an option of classifying piping systems on a two level essentiality criteria or retaining the original three levels. The result has been lack of uniformity which can create problems where there is an exchange of plans, locally prepared specifications, and material between the shipyards. Then too, even with the guidelines provided the shipyards relative to piping systems, there is not uniformity in the assignment of essentiality levels to particular piping systems in the ships. To reduce the problems of shipyard management of quality assurance based on level of essentiality criteria, the best solution appears to be adoption of a uniform two level system.

To date, the Bureau of Ships has provided guidelines for assignment of levels of essentiality to piping and hull material and processes. Except for

unusually critical exceptions, similar guidelines have not yet been definitized for electrical and mechanical equipment and systems. Assignments now being made in the shipyards are not uniform and result in varying degrees of inspection, standards of acceptance, and assurance.

Feedback is represented by a closed loop information system through which specific quality results are measured, analyzed, and fed back to the proper organizational components of the total quality assurance system. Feedback of defect and failure information provides a basis for effecting corrective action in the responsible design, material, manufacture, or inspection area. Though there are a number of formal feedback systems which provide failure information on equipment and systems in the fleet, reports of material failures and defects tend to be sporadic. Reports that are made must be delivered to the individuals cognizant over quality in each case for analysis and initiation of corrective actions where definitely required.

The basic areas for control of vendor supplied materials are proper preparation and review of purchase specifications, proper selection of capable vendors, clarification of quality requirements, source inspection, and adequate shipyard receiving inspection. Clarification of quality requirements and adequate shipyard receiving inspection necessarily applies to critical materials received from Government activities as well as from commercial vendors. Waiver of specifications and non-conforming material must not be condoned since they lower the standards of quality efforts. Identification markings are used to assure proper use or application of material and to permit traceability back to the quality documentation.

An inspection system provides uniform, systematic, and planned inspections during the various manufacturing processes and inspection and test of completed work. The designated inspector must be trained and qualified, his

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test equipment must be properly calibrated, and he should have written procedures which show the standards of acceptance and the records to be maintained. Over-inspection and uncoordinated inspection will delay production and add unnecessary costs. Inspection must not be waived as an expedient to meeting production schedules.

Inspection is the process of evaluating the quality of the item produced. Quality assurance audit is the process of analyzing and evaluating quality procedures, methods, and records for the purpose of determining compliance with requirements. Through sampling, audits will provide the assurance that policies, instructions, and procedures are carried out as intended in all functional areas from design to final test. Or, the audit process may be used to evaluate a critical area of the quality system such as non-destructive testing or material identification and control.

The Bureau of Ships is conducting audits of specific areas which provide the greatest contribution to the quality of submarines. In most cases, these audits are also applicable to surface ships. However, there is no attempt to measure the overall effectiveness of the quality assurance plan at the Naval shipyards though this is the intent of pre-award quality assurance audits now being conducted in commercial shipyards.

The Naval shipyards have also developed audit teams for self evaluation. Members of the shipyard teams are subject to assignment to the Bureau of Ships audit team.

Gaining an understanding of the benefits to be realized from practical implementation of the quality assurance program in the shipyards should at least alleviate the first serious obstacle - increased cost. Since there has been an increase in emphasis on the need for always meeting specifications,

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the initial effect was increase in costs due to increased inspection effort with an associated increase in detection and ripping out of unsatisfactory work in order to deliver ships which met the required standards. The quality assurance program was developed to assure quality workmanship and material and to prevent the need for rework. Rework is at least an order of magnitude more expensive than doing the job right in the first place. A few serious material replacement programs will pay the cost of an adequate quality assurance program. The theme of quality assurance is "prevention, not detection."

The cost of quality must be commensurate with the value of the quality achieved. The costs of effecting levels of quality in ships, and their equipment and systems, must be subjected to value analysis studies. Standards and specifications must be met on each and every job, but complete inspection and verification of quality is not required for the greater majority of ship work. Where we are concerned with critical equipment, systems, and processes with high levels of essentiality in terms of physical stress, mission, and safety, we must consider intangible as well as tangible costs of material failures. The decision as to the level of quality must be based on the answer to the question, "What happens if we do not have adequate assurance?" In many cases, the decision must be to take every possible action to secure complete assurance of quality with the Navy being prepared to accept the costs of obtaining such confidence.

Too often, there is the feeling in our shipyards that Navy specifications are a desirable goal rather than a firm requirement. There are occurrences of lack of understanding as to what the specification requirements are and why it is important that they be met. In some instances, it has been impracticable to conform to particular specification requirements

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and individuals have taken it upon themselves to waive the requirements without feeding back either the problem or their decisions to proceed. All of these things have brought about deterioration of quality under the pressure of production schedules and cost reduction drives, and because of inadequate quality assurance programs.

Formal training in the aspects and purpose of quality assurance in our shipyards has been limited since the program is still relatively new. But, the shipyards should increase their quality assurance orientation programs. Simply telling the craftsmen that "this is the way the job must be done" will not achieve its purpose. The craftsman must also know why it is so important that the job must be done that way. It is necessary to improve present conditions by publicizing quality assurance policy, by orientation courses, by taking a firm stand on quality from the top of the organizations to the bottom, and by getting across the need for doing the job right the first time.

The zero defects program can be an important booster to quality assurance efforts to motivate everyone to get the job done right - the first time. The overall plan of the shipyard should be to build the zero defects program with the intention of sustaining it. It should be sold to the shipyard employees with a sincere and honest approach and should not be overpromoted initially. New employees should be indoctrinated in the program as they are hired. Merely spending money on the program will not be nearly as effective as management support, supervisory follow-up, and proper acknowledgement of individual and group achievement. The magnitude of the task of planning, implementing, and sustaining the program could easily be underestimated.

Based on inspection evidence that many specification requirements were

not being met, the Chief, Bureau of Ships has stated:

> It is my policy that ships will be built, converted, repaired, and overhauled in conformance with the specifications....Specifications are not to be considered as desirable goals which should be met but rather as minimum standards which must be met or exceeded.[2]

This statement implies only one level of quality: 100%. When plans and specifications are met on the job, the result is quality no matter what degree of inspection or assurance of quality is used. Just because no inspection or no quality assurance documentation is designated for a particular job does not mean that it is not important. An attitude of pride in workmanship and meeting all specifications on every job will reduce shipyard costs as well as increase the confidence of the fleet in the capabilities of our shipyards. The goal in each construction or overhaul effort must be "a ship's worth of confidence."

[2]Department of the Navy, Bureau of Ships Instruction 9020.27, Conformance with Specifications, (Washington: 6 September 1963).

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APPENDIX I

QUALITY AND RELIABILITY ASSURANCE DEPARTMENT[1]

Quality and Reliability Assurance Officer

The Quality and Reliability Assurance Officer is responsible to the Shipyard Commander for the organization, administration, and supervision of the Quality and Reliability Assurance Department, and for such other work as may be assigned by the Shipyard Commander.

Duties

Planning, executing, and monitoring a quality and reliability assurance program for the shipyard; guidance, integration, and evaluation of the efforts of the Shipyard towards the prevention of defective quality and reliability; investigation and evaluation of quality and reliability problems to determine the fundamental cause, the cost, the scope, and the significance of the problem; maintaining standards of measurement and performing calibration; developing a quality and reliability assurance functions such as inspections, physical and chemical tests, qualification tests, nondestructive tests, witnessing of formal operational tests as assigned; failure mode and effect analysis, reliability prediction analysis, maintainability analysis and process capability studies; technical requirements for metal fabrication and thermal joining processes; execution of such research, development, test and evaluation programs as are assigned. However, in shipyards with a Nuclear Power Division, quality assurance for nuclear reactor plants is the responsibility of the Nuclear Power Superintendent as assigned in Article 620H.

Organization

The organization of the Quality and Reliability Assurance Department consists of:

(a) Quality and Reliability Assurance Engineering and Analysis Division.
(b) Inspection Division.
(c) Laboratory Division.
(d) Metals Fabrication Division.

Chief Quality and Reliability Assurance Engineer.

The Chief Quality and Reliability Assurance Engineer is responsible to the Quality and Reliability Assurance Officer for the efficient performance and coordination of all activities of the Quality and Reliability Assurance Department. He is the principal advisor to the Quality and Reliability Assurance Officer on administrative and technical matters.

[1]Department of the Navy, Bureau of Ships Instruction 5450.14A. Standard U. S. Naval Shipyard Regulations. (Washington: 18 March 1958).

Quality and Reliability Assurance Engineering and Analysis Division

The Head of the Quality and Reliability Assurance Engineering and Analysis Division is responsible to the Quality and Reliability Assurance Officer for:

(a) Coordinating, planning, executing and monitoring a systematic, comprehensive, and economical quality and reliability assurance program for the shipyards.

(b) Investigation of quality and reliability problems to ascertain their cause, cost and scope, evaluating their significance, and recommending corrective action.

(c) Developing an integrated plan for a Shipyard program for the prevention of quality and reliability defects.

(d) Coordinating the development of standards for quality of work for assurance of applicability, adequacy and economy.

(e) Developing a quality and reliability assurance indoctrination and training program for the shipyard.

(f) Knowing the latest quality and reliability measurement developments, applications and technologies and initiate their use where applicable.

(g) Coordinating and administering quality and reliability assurance surveys within the Shipyard.

(h) Coordinating and participating in the evaluation of contractor's quality and reliability assurance systems for complex items procured by the Shipyard.

(i) Perform failure mode and effect analysis.

(j) Perform reliability prediction analysis.

(k) Perform maintainability analysis.

(l) Perform process capability studies.

Inspection Division

The Head of the Inspection Division is responsible to the Quality and Reliability Assurance Officer for:

(a) Directing the preparation and issuance of inspection instructions specifying the types and frequencies of inspections to be performed to assure conformance to prescribed standards of quality.

(b) Conducting or witnessing assigned tests and inspections in accordance with paragraph a.

(c) Transmitting and amplifying to the inspectors the applicable criteria for acceptance or rejection.

(d) Identifying those areas where acceptance criteria are not definitive and initiating action to obtain clear criteria.

(e) Developing and implementing specific methods and procedures for inspection data collection, tabulation, analysis and dissemination in order to identify quality problems and indicate quality levels.

Laboratory Division

The Head of the Laboratory Division is responsible to the Quality and Reliability Assurance Officer for:

(a) Providing scientific and technological service and guidance to the Shipyard.

(b) Directing Instrument Calibration Programs for measuring and testing equipment.

(c) Performing those quality and reliability assurance tests and actions which require laboratory or scientific services.

(d) Conducting assigned research, development, tests and evaluation programs as directed.

Metal Fabrication Division

The Head of the Metal Fabrication Division is responsible to the Quality and Reliability Assurance Officer for:

(a) Technical requirements for processes involving the fabrication of joining of metals, such as bending, forming, welding, and silver brazing.

(b) Establishing and interpreting standards for quality of work in the metal fabrication and joining processes.

(c) Establishing of qualification requirements for mechanics and equipment in the metal fabrication and joining processes.

(d) Development or improvement of welding methods, materials, processes, practices and equipment.

(e) Prescribe preventive requirements to minimize quality defects in the fabrication or joining of metals.